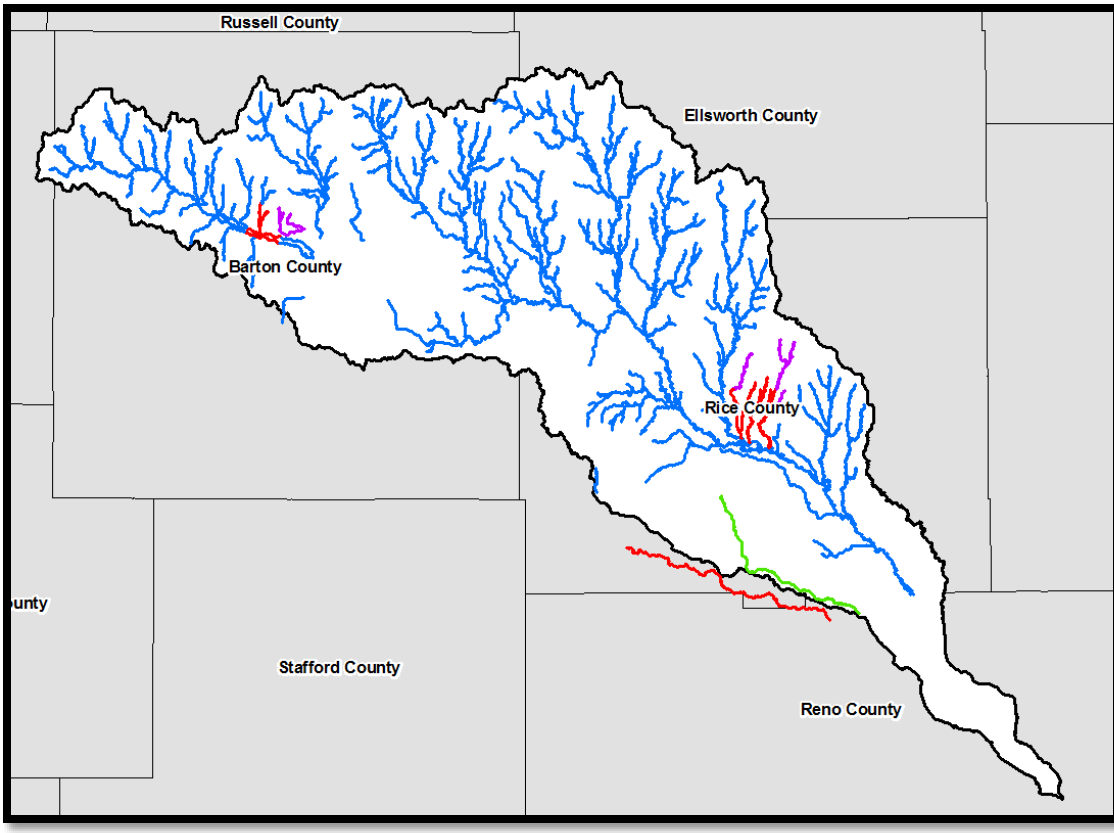
HYDROLOGY REPORT
COW WATERSHED



UNDER CONTRACT WITH:
KANSAS DEPARTMENT OF AGRICULTURE
Division of Water Resources
CONTRACT NO: EMW-2015-CA-00078

PREPARED BY:
AMEC FOSTER WHEELER ENVIRONMENT & INFRASTRUCTURE INC.
100 SE 9TH STREET, SUITE 400
TOPEKA, KS 66612

March 2016

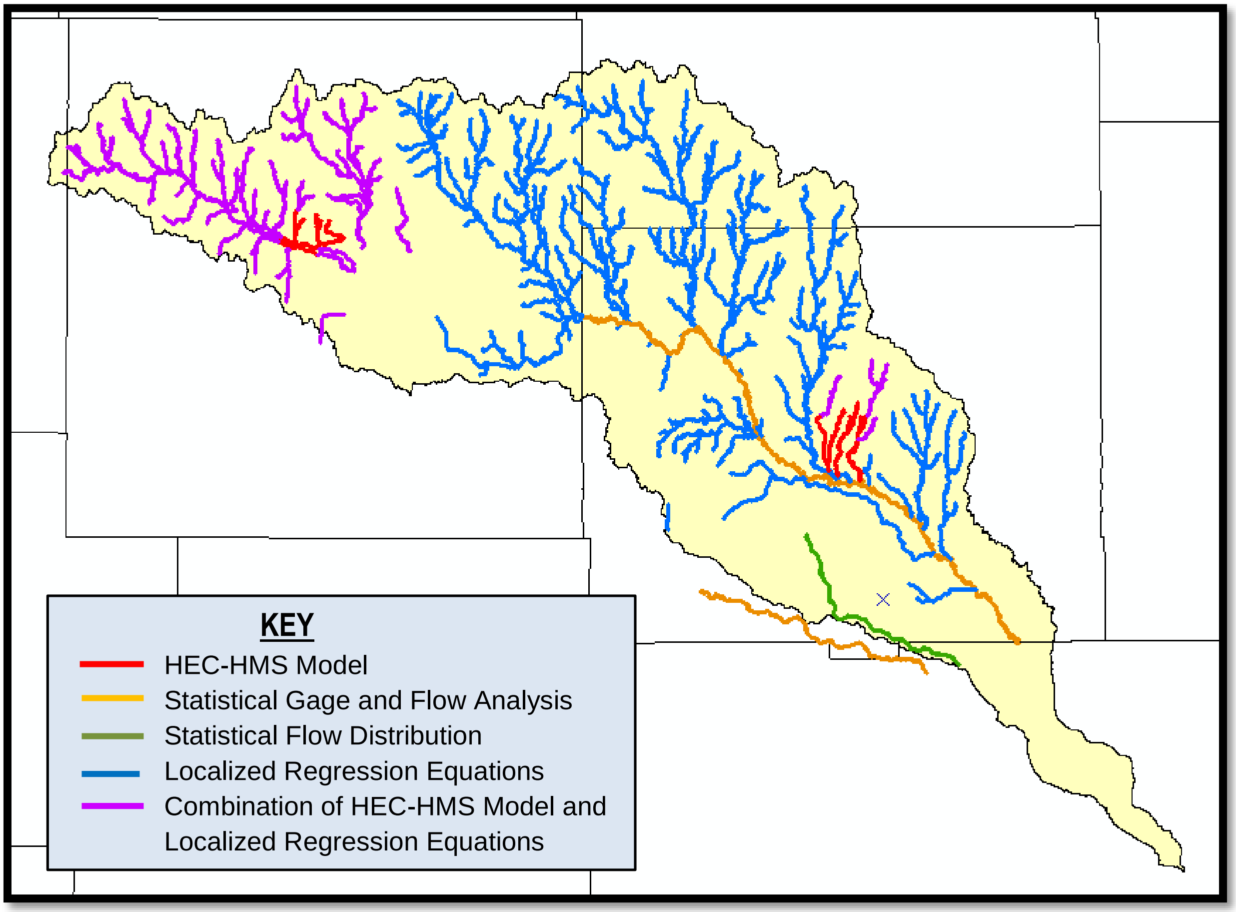
INTRODUCTION

This report presents the hydrologic analyses for the detailed Zone AE and approximate Zone A designated streams in the Cow Watershed (HUC8 11030011), which lies within the Kansas Counties of Barton, Ellsworth, Reno, and Rice. This project consists of new detailed hydrologic and hydraulic studies using current watershed characteristics and new detailed topography for 51 stream miles of streams that will be modeled by detailed methods resulting in Zone AE floodplains with a floodway, and 912 stream miles of streams that will be studied by approximate methods resulting in updated Zone A floodplains. It was requested to perform enhanced hydrology on approximately 7.0 stream miles of Zone A streams based on a rainfall-runoff model, and to distribute enhanced hydrology on approximately 15.6 stream miles of Bull Creek, a Zone A stream, based on the extrapolation of flows from an effective Letter of Map Revision (LOMR). In addition, statistical gage analysis was performed for approximately 66.4 stream miles of Cow Creek, which is a Zone A stream. For streams not included in a detailed hydrologic study, approximate Zone A hydrology was performed using localized regression equations, generated from the results of the detailed rainfall-runoff models that were developed for this watershed. A summary of the streams that were studied is shown in Table 1. A figure that shows the type of hydrologic method used for each stream is shown in Figure 1.

Table 1: Summary of Methods

Study Area/Flooding Source	Stream Miles	Hydrologic Method
Arkansas River	18.1	Statistical Gage and Flow Analysis
Blood Creek	3.3	Rainfall-Runoff Model (HEC-HMS)
Bull Creek	15.6	Statistical Flow Distribution
Cheyenne Bottoms Tribs 2, 2.1, and 2.3	7.0	Rainfall-Runoff Model (HEC-HMS)
Cow Creek	66.4	Statistical Gage and Flow Analysis
Salt Creek	5.9	Rainfall-Runoff Model (HEC-HMS)
Salt Creek Trib 1	1.0	Rainfall-Runoff Model (HEC-HMS)
Shop Creek	2.2	Rainfall-Runoff Model (HEC-HMS)
Shop Creek Trib 1	1.4	Rainfall-Runoff Model (HEC-HMS)
Surprise Creek	4.7	Rainfall-Runoff Model (HEC-HMS)
Surprise Creek Trib 1	3.4	Rainfall-Runoff Model (HEC-HMS)
Owl Creek	6.9	Rainfall-Runoff Model (HEC-HMS)
Owl Creek Trib 2	1.1	Rainfall-Runoff Model (HEC-HMS)
Unnamed Slough	3.0	Rainfall-Runoff Model (HEC-HMS)
Various Zone A Streams	207.1	Combination of HEC-HMS and Localized Regression Equations
Various Zone A Streams	615.7	Localized Regression Equations

Figure 1- Type of Hydrologic Modeling for Each Stream in Cow Watershed



This hydrologic study was performed to develop peak discharges for the 10%, 4%, 2%, 1%, 1%+ and 0.2% annual chance storm events. The peak discharges computed from this analyses shall be used in developing the hydraulic analyses for the streams within this study.

The extents of the approximate Zone A studies include those streams currently designated by FEMA, plus the conveyances with drainage areas equal to or greater than 1-square mile of drainage area; excluding those "conveyances" that have contributing drainage areas of less than one square mile, have an average flood depth of less than one foot, and/or lack a defined channel. A detailed adjustment of the stream network relative to aerial photography and LiDAR was completed to ensure proper streamline alignment and extent.

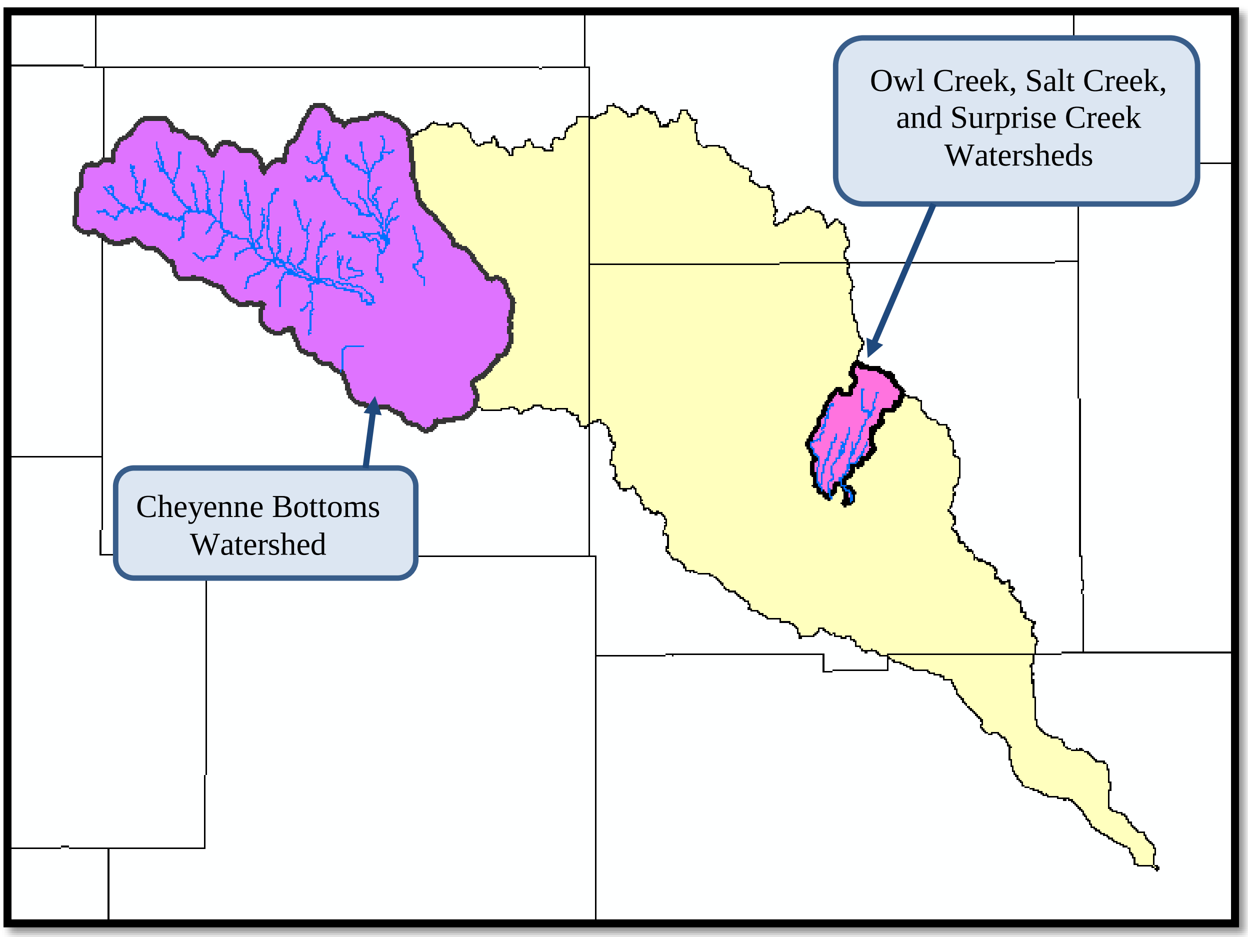
The current effective Flood Insurance Study (FIS) Report for Barton County is dated September, 2009. The current effective FIS Report for Ellsworth County is dated August, 2009. The current effective FIS Report for Reno County is dated January, 2010. A revised draft FIS Report for portions of Reno County was completed in 2011; based on a study undertaken in 2009 by the Kansas Department of Agriculture. This study is currently on hold as it is waiting on levee certification, but can be used in some cases as best available data. The current effective FIS Report for Rice County is dated September, 1997.

General Rainfall-Runoff Model

The rainfall-runoff model HEC-HMS version 4.1 (Reference 2), developed by the USACE, was used for the two detailed rainfall-runoff models within this project, which include the Cheyenne Bottoms Watershed and the Owl Creek, Salt Creek, and Surprise Creek Watersheds. Figure 2 shows the extent of these two rainfall-runoff models. Amec Foster Wheeler used HEC-HMS to generate sub-basin runoff hydrographs for the 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% chance 24-hour SCS Type II rainfall events. These runoff hydrographs were routed and combined along the studied streams to produce the peak discharges.

Subbasin boundary delineations were based on topography obtained as 1-meter LiDAR through the Kansas Data Access and Support Center (DASC). Subbasin boundaries were first delineated using automated GIS processes including HEC-GeoHMS (Reference 3) and ArcHydro (Reference 4) based on LiDAR Digital Elevation Models (DEM), and then manually edited as needed based on storage considerations and the most recent aerial photography available.

Figure 2: Boundaries of the Cheyenne Bottoms Watershed and the Owl Creek, Salt Creek, and Surprise Creek Watersheds.



RAINFALL

The rainfall depths, shown in Table 2, were computed using rainfall grids developed by NOAA as part of Atlas 14: Precipitation-Frequency Atlas of the United States (Reference 5). The depths represent an average of all partial-duration grid values within the two areas of the Cow Watershed that are included in the rainfall-runoff models; the Cheyenne Bottoms Watershed and the Owl Creek, Salt Creek, and Surprise Creek Watersheds. Due to the varying rainfall values across the Cow Watershed, separate rainfall depths were determined for each rainfall-runoff model to provide more accuracy to the models.

Rainfall values were also computed using the annual-maximum series. A comparison of these rainfall values to the partial-duration series is shown in Table 3. Since the calculations for the annual-maximum series rely on only one flood event for each year, and since the lower storm events are more likely to have multiple flood events in a given year, the partial-duration series would be more appropriate for lower frequency events. In addition, since the two values are predominately the same for the higher storm events, it was determined that the partial-duration rainfall values would be appropriate for all storm events in this study.

Table 2: SCS Type II 24-hour Rainfall Depths

Event	Cheyenne Bottoms Watershed Depth (inches)	Owl, Salt, and Surprise Creek Watersheds Depth (inches)
10-year	4.3	4.5
25-year	5.2	5.5
50-year	6.0	6.3
100-year	6.9	7.1
100-year minus	5.4	5.6
100-year plus	8.4	8.6
500-year	9.1	9.3

Table 3: Comparison of Rainfall for Partial-Duration and Annual-Maximum Series

Event	Partial-Duration Series			Annual-Maximum Series		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Cheyenne Bottoms Watershed						
10-year	4.0	4.3	4.4	3.9	4.2	4.4
25-year	4.9	5.2	5.4	4.9	5.2	5.4
50-year	5.6	6.0	6.3	5.6	6.0	6.2
100-year	6.5	6.9	7.1	6.5	6.9	7.1
100-year upper	8.4	9.0	9.1	8.4	8.9	9.1
500-year	8.6	9.1	9.4	8.6	9.1	9.4
Owl Creek, Salt Creek, and Surprise Creek Watersheds						
10-year	4.3	4.5	4.8	4.3	4.4	4.4
25-year	5.3	5.5	5.8	5.3	5.4	5.8

Table 3: Comparison of Rainfall for Partial-Duration and Annual-Maximum Series						
Event	Partial-Duration Series			Annual-Maximum Series		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
50-year	6.1	6.3	6.6	6.1	6.2	6.6
100-year	7.0	7.1	7.5	7.0	7.1	7.5
100-year upper	9.0	9.1	9.4	9.1	9.1	9.4
500-year	9.2	9.3	9.6	9.1	9.3	9.6

The 100-year minus and 100-year plus rainfall depths were computed by using the 100-year rainfall depth and the 95% upper confidence interval for the 100-year rainfall depth published in Atlas 14, along with the known sample size of 1,000 data sets used in Atlas 14, to compute the standard deviation. This computed standard deviation was then used to calculate the 84% lower and 84% upper confidence limits, which are the values used for the 100-year minus and 100-year plus rainfall depths, respectively.

RAINFALL LOSS

The U.S. Department of Agriculture Soil Conservation Service (SCS) Curve Number (CN) Method was used to model rainfall loss (Reference 8). The curve number is a function of both hydrologic soil group and land use. The table used to determine the CN value from the soil hydrologic soil group and land use is located in Table 4. The curve number tables used assume an antecedent moisture condition (AMC) of II as it is representative of typical conditions, rather than the extremes of dry conditions (AMC I) or saturated conditions (AMC III).

The value for initial abstraction was left blank in the HMS input file. Per the HMS documentation, doing so will cause the program to calculate the initial abstraction as 0.2 times the maximum potential retention (S) which is calculated from the curve number as S = (1000/CN) – 10. This method is based on empirical relationships developed from the study of many small experimental watersheds, and is a commonly accepted method of estimating the initial abstraction.

SOILS DATA

Soils data was obtained in shapefile and database format from the United Stated Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) website (Reference 6). Typical soils in the study area consist of hydrologic soil groups A, B, C and D; with the majority being Types B and C.

LAND USE

Land use was determined using a combination of data from the National Land Cover Dataset (NLCD) website (Reference 7) and aerial photography. Fifteen land use designations were utilized to develop the CN values for each subbasin. The CN values were taken from “TR-55 Urban Hydrology for Small Watersheds” Table 2-2 (Reference 8). The land use designations are located in Table 4. It should be noted that the CN values were first calculated using AMC II conditions, as represented in Table 4.

Table 4: CN Land Use and Soil Drainage Class Table				
	Weighted CN (Includes Impervious)			
Land Use Description	A	B	C	D
Open Water	98	98	98	98
Developed, Open Space	51	68	79	84
Developed, Low Intensity	57	72	81	86
Developed, Medium Intensity	77	85	90	92
Developed, High Intensity	89	92	94	95
Barren Land	77	86	91	94
Deciduous Forest	30	55	70	77
Evergreen Forest	30	55	70	77
Mixed Forest	30	55	70	77
Shrub/Scrub	43	65	76	82
Herbaceous	43	65	76	82
Hay/Pasture	49	69	79	84
Cultivated Crops	65	75	82	86
Woody Wetlands	36	60	73	79
Emergent Herbaceous Wetlands	36	60	73	79

The soil and land use data were combined using GIS processes in which specific curve numbers were defined for each soil-land use relationship shown in the CN Land Use and Soil Drainage Class Table (Table 4). Area-weighted curve number values were computed for each subbasin using GIS processes. The area weighted CN values were used in the HEC-HMS models.

RAINFALL TRANSFORM (HYDROGRAPH)

The runoff was transformed into a hydrograph using the Clark Unit Hydrograph method or the SCS Unit Hydrograph Method, depending on the watershed characteristics. The project area contains many small farm ponds in addition to the larger dams/storage areas included in the models. The Clark Unit Hydrograph method allows the models to account for surface storage attenuation where the inclusion of detailed storage areas is not feasible. Table 5 represents the Clark's Ratio classification, which was used to define the Clark's ratio for each subbasin; based on basin slope, storage considerations, and land use type.

The time of concentration for each subbasin was calculated using the methodology outlined in Chapter 15: Time of Concentration of the National Engineering Handbook (Reference 9). A GIS process was utilized to calculate the longest flow path within any given subbasin. The longest flow paths were then manually edited based on contour data and visual inspection of aerial photography to produce an effective time of concentration line. The total time of concentration consists of the sum of the travel times for sheet flow, shallow concentrated flow, and channel flow. Sheet flow lengths were assigned to be approximately 300 feet or less using the aerial imagery as a guide. The division between shallow concentrated flow and channel flow was defined based on watershed features exhibited on the aerial images and topography. In certain situations, it was necessary to define multiple shallow concentrated and channel flow regimes for a given longest flow path. Time of concentration over water bodies was calculated using wave velocity.

Table 5: Classification To Define Clark's Ratio			
Subbasin Description	**Minimum % Slope[1]**	**Maximum % Slope[1]**	**Clarks Ratio**
Highly Developed	0	3	0.3
Highly Developed	3	6	0.25
Highly Developed	6	-	0.2
Residential	0	3	0.35
Residential	3	6	0.3
Residential	6	-	0.25
High Storage Residential[2]	0	3	0.4
High Storage Residential[2]	3	6	0.35
High Storage Residential[2]	6	-	0.3
Rural Steepland	4	8	0.45
Rural Steepland	8	-	0.4
Rural Flatland	0	2	0.6
Rural Flatland	2	4	0.5
High Storage Rural Steepland[2]	4	8	0.5
High Storage Rural Steepland[2]	8	-	0.45
High Storage Rural Flatland[2]	0	2	0.65
High Storage Rural Flatland[2]	2	4	0.55

1- Percent Slope is based on the average slope of the basin.
2- Storage areas that are represented separately within the HMS model are not considered when evaluating Basins with "High Storage"

The parameters of flow area and wetted perimeter are required inputs for calculating the flow velocity used in the channel time of concentration calculations. Typical channel cross sections were defined for each subbasin, and trapezoidal cross-sections were defined from the project topography. In order to calculate the flow area and wetted perimeter, several factors need to be considered. For open channel flow, a trapezoidal channel shape was selected based on examination of aerial photography and topography. Channel width was approximated by close visual inspection of the aerial photography and LiDAR topography.

HYDROGRAPH ROUTING

The Muskingum-Cunge channel routing method was used for routing runoff through all reaches in the modeling. The channel geometry, slope, and hydraulic roughness were assigned, based on the LiDAR data and the aerial images. Eight-point cross sections were developed, based on examination of aerial photography and topography. Manning's channel roughness values for the routing reaches were selected based off the aerial photography.

CHEYENNE BOTTOMS WATERSHED

Due to the unique characteristics of Cheyenne Bottoms, which is a large wetland occupying approximately 41,000 acres, and the detailed Zone AE streams within the drainage area of Cheyenne Bottoms, Amec Foster Wheeler decided to develop a HEC-HMS model for the entire area that flows into Cheyenne Bottoms. This area includes four detailed Zone AE streams; which consist of Blood Creek, Unnamed Slough, Shop Creek, and Shop Creek Trib 1; and three Enhanced Hydrology Zone A streams; all located near or in the City of Hoisington. The detailed hydrologic study of the Cheyenne Bottoms watershed, which is located in Barton County, has a total drainage area of approximately 228 square miles. The Cheyenne Bottoms watershed was divided into 132 subbasins, ranging from 0.1 square mile to 20.3 square miles, with the majority of the subbasins being rural. Fourteen of the subbasins contain urbanized areas within the City of Hoisington. The Cheyenne Bottoms wetland was treated as a reservoir with three distinct storage areas, each discharging to the outlet channel, located in the southeast corner of the wetland, via box culverts. A diversion channel enters the southwest corner of the wetland, allowing water from the Walnut River to enter Cheyenne Bottoms.

Rainfall and Aerial Reduction

Areal reduction of the point rainfall depths was not deemed necessary for the Cheyenne Bottoms watershed study since the rainfall depths were generated using the Cheyenne Bottoms watershed boundary.

Diversion Channel Routing

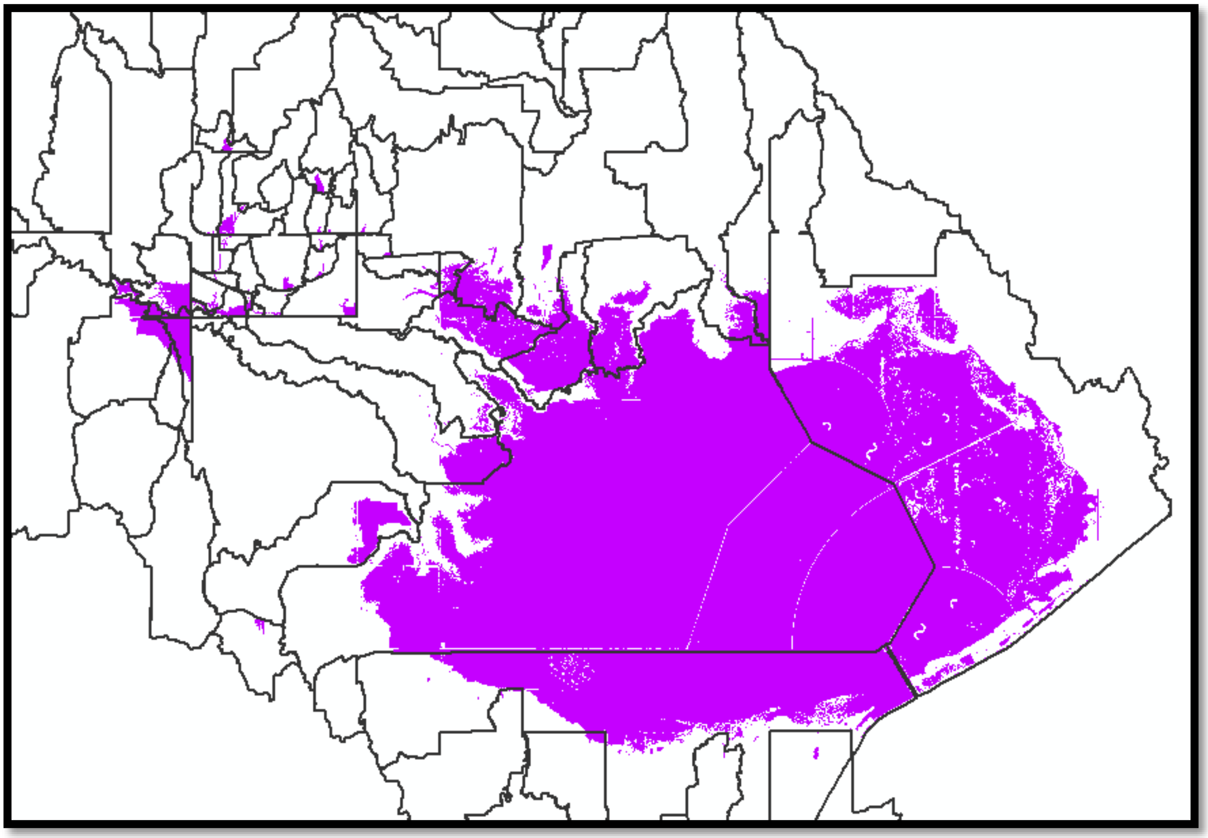
A diversion channel enters the southwest corner of Cheyenne Bottoms, allowing water from the Walnut River to enter Cheyenne Bottoms. A survey of the diversion channel inlet structure was conducted by Amec Foster Wheeler. The inlet structure consists of three box culverts, with sliding gates. The maximum flow through the inlet structure was calculated using the Manning's equation. During a significant rainfall event, only the discharge from the three box culverts will enter the diversion channel, due to the topography in the vicinity of the inlet structure. When considering the vast size of the Cheyenne Bottoms wetland, the maximum flow through the inlet structure adds a relatively small amount of inflow to Cheyenne Bottoms Therefore, Amec Foster Wheeler decided to take a conservative approach, and use the maximum flow through the inlet structure as the flow in the diversion channel during all the storm events. USGS stream gage Station 07142019 is located along the diversion channel. Unfortunately, the gage only has 7 years of record and cannot be considered for a gage analysis or used for comparison purposes. It should be noted that the actual drainage area for the diversion channel is unknown.

Storage Routing

Twenty six storage areas were modeled in the Cheyenne Bottoms watershed hydrologic model. Twenty two storage areas represent storage behind dams and road/railroad embankments located along the Zone AE designated streams and the Enhanced Hydrology Zone A Streams. One storage area represents storage behind one large embankment located west of Cheyenne Bottoms. Three storage areas represent storage within Cheyenne Bottoms. The three storage areas for Cheyenne Bottoms each discharge to the outlet channel via double box culverts. Specifications for dam tops, associated spillways, and associated outlet structures were included in the HEC-HMS model, where applicable. Detailed survey information, obtained by Amec Foster Wheeler, was used for all outlet structures of the storage areas located along the Zone AE designated streams. Survey information, obtained by Amec Foster Wheeler, was also used for the outlet structures of the storage areas not located along Zone AE designated streams, where access to the structures was available. Information on the dam tops and spillways of these storage areas were obtained using LiDAR topography. All other storage areas throughout the basin were represented using the Clark Unit Hydrograph method previously described.

Figure 3 illustrates the extent of the maximum water elevation during the 1% annual chance storm event for all the storage areas included in the Cheyenne Bottoms watershed HEC-HMS model, along with subbasin boundaries.

Figure 3- Extent of Maximum Water Elevation of Modeled Storage Areas during 1% chance storm event.



Flow Comparison

Table 6 provides a comparison of 1% annual chance peak discharges from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 6: Comparison of 1% Annual Chance Discharge				
	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)	
Location	FIS	HMS	FIS	HMS
Shop Creek				
At NW 120 Road	N/A	3.16	N/A	1,327
At W 9th Street	4.55	3.50	2,770	1,452
At W 2nd Street	N/A	3.98	N/A	1,630
At Union Pacific Railroad	5.22	5.23	2,990	2,173
At Mouth	N/A	5.37	N/A	2,256
Shop Creek Trib 1				
At W Cheyenne Street	N/A	0.71	N/A	421
At W 9th Street	N/A	1.06	N/A	602
At Mouth	NA	1.19	N/A	539
Unnamed Slough				
At NW 10 Avenue	N/A	16.34	N/A	2,351
At Confluence with Shop Creek	N/A	21.74	N/A	4,884
At S Vine Street	N/A	22.03	N/A	4,849
At S Main Street	N/A	22.05	N/A	4,847
At East Keystone Road	NA	22.77	N/A	4,893

Table 6: Comparison of 1% Annual Chance Discharge				
	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)	
Location	FIS	HMS	FIS	HMS
Blood Creek				
At NW 10 Avenue	N/A	77.78	N/A	5,392
At S Main Street	N/A	77.86	N/A	5,376
*Discussion of regression equations is included later in the report.				

Flow values for Shop Creek are slightly lower than the flows described in the effective FIS Report. This is presumably caused by the inclusion of storage areas behind road embankments in the HEC-HMS model, which results in a more accurate representation of flows in flat drainage areas such as these, which were most likely not included in the previous study. This may also be due to more detailed topography and the incorporation of new modeling methods. The attenuated flows for Unnamed Slough and Blood Creek are likely caused by the inclusion of storage areas along the streams and the limited area of flow contribution (a bottleneck with areas contributing low flow). Flow values for Shop Creek Trib 1, Unnamed Slough, and Blood Creek are not included in the effective FIS report.

Owl Creek, Salt Creek, and Surprise Creek Watersheds

The detailed hydrologic study of the Owl Creek watershed in Rice County, Kansas has a total drainage area of approximately 12.5 square miles. This detailed study includes Owl Creek and Owl Creek Trib 2. The Owl Creek watershed was divided into 28 subbasins. Two of the subbasins contain urbanized areas within the City of Lyons, while the remaining sub-basins are predominately rural areas. The sub-basins range from 0.064 to 1.38 square miles.

The detailed hydrologic study of the Salt Creek watershed in Rice County, Kansas has a total drainage area of approximately 4.3 square miles. This detailed study includes Salt Creek and Salt Creek Trib 1. The Salt Creek watershed was divided into 10 sub-basins. Six of the subbasins contain urbanized areas within the City of Lyons, while the remaining sub-basins are predominately rural. These sub-basins range from 0.16 to 1.03 square miles.

The detailed hydrologic study of the Surprise Creek Watershed in Rice County, Kansas has a total drainage area of approximately 7.5 square miles. This detailed study includes Surprise Creek and Surprise Creek Trib 1. The Surprise Creek watershed was divided into 21 sub-basins. Five of the subbasins contain urbanized areas within the City of Lyons, while the remaining sub-basins are primarily rural areas. These sub-basins ranged from 0.19 to 0.79 square miles.

Rainfall and Aerial Reduction

Areal reduction of the point rainfall depths was not deemed necessary for the Owl Creek, Salt Creek, and Surprise Creek watershed studies since the contributing drainage area would have resulted in insignificant rainfall depth reductions based on the area-depth curves of TP-40.

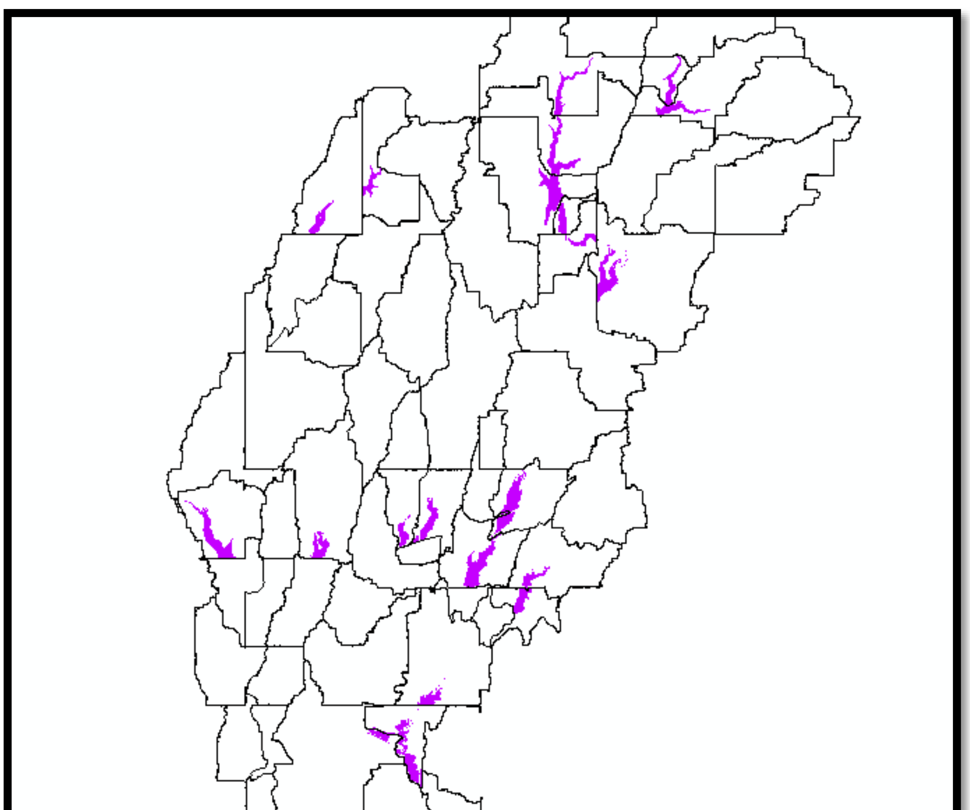
Storage Routing

Fourteen storage areas were modeled in the Owl Creek watershed hydrologic model. Two storage areas were modeled in the Salt Creek watershed hydrologic model. Four storage areas were modeled in the Surprise Creek Watershed hydrology model. These areas represent storage behind dams and road/railroad embankments within the model. The criteria for including storage areas within the model was based on the storage area location, application of the storage area, and the storage volume. Preliminary selection criteria allowed for storage areas in the most upstream portions of the watersheds to be excluded from the model, and represented using the Clark Unit Hydrograph method previously described. Using a higher Clark's Ratio will adequately compensate for restrictions on the outlet hydrograph by a storage area located at or near the outlet of a subbasin. Secondly, after reviewing the spatial characteristics of the potential storage areas along the Zone AE designated streams that are located within the City of Lyons, Amec Foster Wheeler decided not to include the majority of the storage areas within the center of the city in the HEC-HMS model due to the difficulty in modeling the in-line structures. These areas will be further evaluated during hydraulic modeling, and if necessary storage routings of these areas will be completed using unsteady flow HEC-RAS.

Specifications for dam tops, associated spillways, and associated outlet structures were included in the HEC-HMS model, where applicable. Detailed survey information, obtained by Amec Foster Wheeler, was used for all outlet structures of the storage areas located along the Zone AE designated streams. Survey information, obtained by Amec Foster Wheeler, was also used for the outlet structures of storage areas not located along Zone AE detailed streams, where access to the structures was available. Information on the dam tops and spillways of these storage areas were obtained using LiDAR topography.

Figure 4 illustrates the extent of the maximum water elevation during the 1% annual chance storm event for all the storage areas included in the Owl Creek, Salt Creek, and Surprise Creek watersheds HEC-HMS model, along with subbasin boundaries.

Figure 4- Extent of Maximum Water Elevation of Modeled Storage Areas during 1% chance storm event.



Flow Comparison

Table 7 provides a comparison of 1% annual chance peak discharges from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 7: Comparison of 1% Annual Chance Discharge				
	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)	
Location	FIS	HMS	FIS	HMS
Owl Creek				
At Avenue L	N/A	9.19	N/A	3,047
At US Highway 56	N/A	9.70	N/A	3,044
At Avenue M	N/A	10.03	N/A	3,002
At Confluence with Owl Creek Trib 1	N/A	11.23	N/A	3,146
At East American Road	N/A	11.80	N/A	3,168
At Confluence with Little Cow Creek	N/A	12.46	N/A	3,087
Owl Creek Trib 2				
At Avenue L	N/A	0.10	NA	121
At Confluence with Owl Creek	N/A	0.23	N/A	223
Salt Creek				
At Avenue L	N/A	1.48	N/A	913
At Kansas & Oklahoma Railroad	N/A	1.76	N/A	875
At Confluence with Salt Creek Trib 1	N/A	2.20	N/A	1,013
At US Highway 56	N/A	2.55	N/A	1,078
At West Taylor Street	3.27	2.82	2,730	1,109
At East American Road	N/A	3.37	N/A	1,212
At Confluence with Little Cow Creek	N/A	4.40	N/A	1,680
Salt Creek Trib 1				
At Avenue L	N/A	0.20	N/A	136
At Kansas & Oklahoma Railroad	N/A	0.37	N/A	180
Surprise Creek				
At KS Highway 14	N/A	0.97	N/A	545
At Kansas and Oklahoma Railroad	N/A	1.55	NA	821
At West Taylor Street	N/A	1.84	N/A	904
At West American Road	2.09	2.03	1,750	971
At Confluence with Surprise Creek Trib 1	N/A	7.40	N/A	2,333
At Confluence with Little Cow Creek	N/A	7.50	N/A	2,342
Surprise Creek Trib 1				
Approximately 1700 Feet DS of Avenue L	N/A	3.71	N/A	1,444
At Kansas and Oklahoma Railroad	N/A	4.09	N/A	1,448
At West Taylor Street	N/A	4.70	N/A	1,534
At Avenue N	N/A	5.04	N/A	1,581
At Confluence with Surprise Creek	N/A	5.26	N/A	1,716
*Discussion of regression equations is included later in the report.				

Flow values for Salt Creek and Surprise Creek are lower than the flows described in the effective FIS Report. This is presumably caused by the inclusion of storage areas behind road embankments in the HEC-HMS model, which results in a more accurate representation of flows in flat drainage areas such as these, which were most likely not included in the previous study. This may also be due to more detailed topography and the incorporation of new modeling methods. The attenuated flows for Owl Creek are likely caused by the inclusion of storage areas along the streams and the limited area of flow contribution (a bottleneck with areas contributing low flow). Flow values for

Owl Creek, Owl Creek Trib 2, Salt Creek Trib 1, and Surprise Creek Trib 1 are not included in the effective FIS report.

GAGE AND EFFECTIVE FLOW ANALYSIS

There are five USGS gage stations located within the Cow Watershed; one located on the diversion channel into Cheyenne Bottoms, one located on Blood Creek, one located on Plum Creek, and two located on Cow Creek. The gage on Blood Creek is located just upstream of NW 120 Road, near Boyd, Kansas. The gage on Plum Creek is located just downstream of 4th Road, near Holyrood, Kansas. The first gage on Cow Creek is located just upstream of State Highway 4, near Claflin, Kansas. The second gage on Cow Creek is located just downstream of the confluence with Little Cow Creek, near Lyons, Kansas. As previously mentioned, the gage on the diversion channel into Cheyenne Bottoms was not analyzed because it only has 7 years of record, and is not useful for comparison or analysis purposes. A summary of the four gages analyzed is shown in Table 9. Annual peak flow records were obtained from the USGS Water Resources website (Reference 14). The gage near Lyons has a significant period of record in which a confident peak flow frequency analysis was computed. The gage on Blood Creek has just enough years of record in which a confident peak flow frequency analysis could be computed. The other two gages do not have enough years of record for a confident peak flow frequency analysis.

A portion of the Arkansas River is also included in the scope of this project, even though it lies outside of the boundary for the Cow watershed. The extent of the studied stream begins just downstream of 7th Road, southwest of Alden, Kansas, and ends just upstream of West 82nd Road, west of Nickerson, Kansas. Three USGS gage stations located on the Arkansas River were analyzed as part of this study. The furthest upstream gage that was analyzed is located just downstream of Highway 281, in Great Bend, Kansas. The next gage is located just upstream of West 82nd Avenue, near Nickerson, Kansas. The furthest downstream gage that was analyzed is located just downstream of Haven Road, southeast of Hutchinson, Kansas. A summary of these gages is shown in Table 9, as well. Annual peak flow records were obtained from the USGS Water Resources website (Reference 14). The gages at Great Bend and near Hutchinson have significant periods of record in which a confident peak flow frequency analysis could be computed. The gage near Nickerson does not have enough years of record for a confident peak flow frequency analysis.

Table 9: Summary of USGS Stream Gages

USGS Gage Number	Gage Description	Drainage Area (mi^2)	Period of Record
07142900	Blood Creek near Boyd, KS	61	1957-1989
07143200	Plum Creek near Holyrood, KS	19	1957-1977
07142860	Cow Creek near Claflin, KS	43	1967-1988
07143300	Cow Creek near Lyons, KS	499	1929-2015
07141300	Arkansas River at Great Bend	34,356	1941-2015
07142680	Arkansas River near Nickerson	36,015	1997-2015
07143330	Arkansas River near Hutchinson	38,910	1960-2015

Gage analysis were performed on these USGS gages using Bulletin 17B parameters (Reference 10), utilizing the USACE HEC-SSP software (Reference 11).

USGS 07142900

USGS Station 07142900 is located near Boyd, Kansas and has 33 years of record, dating from 1957 to 1989. Frequency flow estimates were calculated for this site, but were only used for comparison purposes as the number of years of record is on the low end of what would be considered suitable to perform a confident analysis, and as the record ended 27 years ago.

USGS 07143200

USGS Station 07143200 is located near Holyrood, Kansas and has 21 years of record, dating from 1957 to 1977. Frequency flow estimates were calculated for this site, but were not used as there is not enough years of record for a confident analysis to be performed, and as the record ended 39 years ago.

USGS 07142860

USGS Station 07142860 is located near Claflin, Kansas and has 22 years of record, dating from 1967 to 1988. Frequency flow estimates were calculated for this site, but were not used as there is not enough years of record for a confident analysis to be performed, and as the record ended 28 years ago.

USGS 07143300

USGS Station 07143300 is located near Lyons, Kansas and has a significant period of record, dating from 1929 to 2015, suitable for computing frequency flow estimates. The record for 1929 was removed from the analysis as it was labeled as a historic peak, and was disconnected from the later years of record. For this study, the expected probability values were selected over the computed curve values because the expected probability produces values higher, thus more conservative, than the computed curve and is recommended for use by Bulletin 17B.

USGS 07141300

USGS Station 07141300 is located at Great Bend, Kansas and has 77 years of record, dating from 1921 to 2015. The first year of record was removed from the analysis as its date was unknown, and it was disconnected from the later years of record. The records for 1941 and 1942 were removed from the analysis as discharge in the stream is affected by a diversion beginning in 1943. The record for 1998 was removed from the analysis as there was no flow recorded. Frequency flow estimates were calculated for this site, but were ultimately used for comparison purposes.

USGS 07142680

USGS Station 07142680 is located near Nickerson, Kansas and has 18 years of record, dating from 1997 to 2015. Frequency flow estimates were calculated for this site, but were not used as there is not enough years of record for a confident analysis to be performed, and as the record ended 28 years ago.

USGS 07143330

USGS Station 07143330 is located near Hutchinson, Kansas and has 56 years of record, dating from 1960 to 2015. Frequency flow estimates were calculated for this site, but were ultimately used for comparison purposes as a detailed study was previously completed for the portion of the Arkansas River near Hutchison, Kansas.

STATISTICAL GAGE ANALYSIS RESULTS

A station, weighted and regional skew was evaluated for all seven of the gages selected for analysis. Table 10 shows a comparison of the 1% annual chance event using the three methods of skew.

Table 10: 1% Annual Chance Comparison of Skew Methods				
USGS ID	DA	Station Skew (cfs)	Weighted Skew (cfs)	Regional Skew (cfs)
07142900	61	8,215	9,573	12,099
07143200	19	11,679	8,025	5,724
07142860	43	9,376	12,678	17,616
07143300	499	25,333	23,277	19,730
07141300	34,356	16,395	27,773	61,666
07142680	36,015	9,409	9,759	10,152
07143330	38,910	30,829	30,797	30,701

The wide range of results in the three skew methods for the gages near Holyrood and Claflin are the result of having insufficient years of record. Therefore, the results from these two analysis were not incorporated into the hydrology for the associated streams. The results for the gage near Boyd, Kansas was compared to the flows at the associated junction (Junction 16) within the HEC-HMS model for the Cheyenne Bottoms watershed. Based on results from the HEC-HMS model, the 1% annual chance flow at Junction 16 is 9,658 cfs, which very closely corresponds to the weighted skew method results for the associated gage. Therefore, the weighted skew method results were chosen for the gage near Lyons, Kansas. The wide range of results in the three skew methods for the gage at Great Bend may be due to the fact that this type of analysis is not intended to be used for streams with drainage areas of this magnitude.

COW CREEK

The effective FIS Report for Rice County, KS does not list flows for Cow Creek. The revised draft FIS Report for Reno County, KS lists flows for Cow Creek at West 82nd Avenue, which is downstream of the Reno County line and the streams included in this study.

Only the gage at Lyons, Kansas had enough years of record for a confident flow frequency analysis. The results from the gage analysis and the flows described in the revised draft FIS Report were then interpolated and extrapolated to produce flows at various locations along Cow Creek. The weighted skew method results were chosen for the gage, as the flows were close to the average of all the results and appeared the most appropriate for all gages analyzed. The Drainage Transfer Method was utilized to interpolate flows upstream of the Lyons gage, beginning at the confluence with Little Cheyenne Creek and extending downstream to the gage location. The flows were computed using the following equation for unregulated streams, described in The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites (Reference 13), which utilizes flows from only the Lyons gage.

$Q_u = Q_d * (DA_u / DA_d)^b$

Where:

Q_u = peak discharge at the upstream drainage point of interest, in cubic feet per second

Q_d = peak discharge at the downstream gage location, in cubic feet per second

DA_u = total area that contributes runoff to the upstream drainage point of interest, in square miles

DA_d = total area that contributes runoff to the downstream gage location, in cubic feet per second.

b = Area Transfer Coefficient from the USGS Regression Equations for Kansas (Reference 1)

For example, b equals 0.462 for the following Kansas regression equation: $Q_{1\%}=1.16(A)^{0.462}(P)^{2.250}$

For a selected basin, the average mean annual precipitation (P) is the same and the flow ratio between two locations can be described as follows. $Q_1 / Q_2= (DA_1 / DA_2)^{0.462}$

Since there is no USGS Kansas Regression Equation for the 0.2% annual chance storm event, the Area Transfer Coefficient was extrapolated for the 0.2% storm event using the best-fit curve for the coefficients of the other storm events.

The Uncontrolled Segment Interpolation Procedure was utilized to interpolate flows between the Lyons gage and West 82nd Avenue, which is across the Reno County line. It should be noted that the extent of this study ends at the Reno County line for Cow Creek. The flows were computed using the following parameters, which are described in Table 4 of the USGS Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations (Reference 12).

$$B_s = \frac{B_u(DA_d - DA_s) + B_d(DA_s - DA_u)}{DA_d - DA_u}$$

$$Q_{sb} = Q_{sr} + B_s$$

Where:

B = bias; measured/calculated flow minus regression equation flow, in cfs

DA = total area that contributes runoff to the location of interest, in square miles

Q_{sr} = regression equation flow for ungagged drainage point of interest, in cfs

Q_{sb} = calculated flow for ungagged drainage point of interest, in cfs

The revised draft FIS report does not list a flow for the 1% plus annual chance storm event. However, the Hydrologic Frequency Analysis Report for Cow Creek and the Arkansas River conducted by the USACE Tulsa District for the City of Hutchinson, Kansas in May of 2010, indicates that the frequency discharge values for Cow Creek at Hutchison were developed by adding a multiplier to the frequency discharge values for Cow Creek at Lyons, to account for the local runoff from the Hutchinson subarea, as determined from a HEC-HMS hydrological model analysis. Therefore, the multiplier used to determine the 1% annual chance storm event for Cow Creek at Hutchinson was used to develop the peak flow for the 1% plus annual chance storm event for Cow Creek at Hutchinson.

Table 11 represents the peak discharges computed as part of this statistical analysis, which incorporates analysis from the gages and existing detailed studies.

Table 11: Statistical Analysis Results for Cow Creek							
Location	Drainage Area (sq. mi.)		Peak Annual Chance Discharges (CFS)				
		10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1%+ Annual Chance	0.2% Annual Chance
At Confluence with Little Cheyenne Creek	122	3,729	6,305	8,881	12,147	14,521	23,222
At Confluence with Calf Creek	178	4,470	7,527	10,586	14,464	17,290	27,630
At Confluence with Plum Creek	286	5,609	9,396	13,191	17,996	21,513	34,345
Just US of Confluence with Spring Creek	352	6,194	10,353	14,521	19,799	23,668	37,771
USGS Gage near Lyons	499	7,328	12,201	17,090	23,277	27,826	44,374
At Confluence with Dry Creek	563	9,849	16,077	21,722	28,719	34,359	50,730
At West 82nd Avenue	629	12,400	20,000	26,400	34,200	40,904	57,100

ARKANSAS RIVER

The revised draft FIS Report for Reno County, Kansas lists flows for the Arkansas River at Hutchinson, which is downstream of the portion of the Arkansas River that is included in this study.

Only the gage near Hutchinson, Kansas resulted in a confident flow frequency analysis, based on the years of record and relative consistency of the results for the various skew methods. However, the flows listed in the revised draft FIS report for Reno County, which are based on a detailed study conducted in 2010, lists flows that are slightly higher than the flows resulting from the gage analysis. Therefore, the flows listed in the revised draft FIS report were chosen for use in this study's hydraulic analyses as they are slightly more conservative and consistent with Reno County. The portion of the Arkansas River that is included in this study adds very little drainage area from beginning to end. The soil types in this area are relatively sandy. The annual mean precipitation increases as you move downstream. With all of these characteristics in mind, it is very likely that attenuation occurs through the extent of the Arkansas River that is included in this study. Therefore, Amec Foster Wheeler deemed it appropriate to use the peak flows listed in the revised draft FIS report for the Arkansas River near Hutchinson, Kansas as the peak flows along the entire extent of the stream included in this study. The revised draft FIS report does not list flows for the

1% minus and 1% plus chance storm events. The 1% minus and 1% plus weighted skew method results for the gage near Hutchinson, Kansas were compared to the 1% weighted skew method results. A multiplier was developed for the 1% minus and 1% plus storm events by calculating the percent difference in the 1% minus and 1% plus flows as compared to the 1% flow. These multipliers were then applied to the effective 1% annual chance flow for the portion of the Arkansas River included in this study, to determine the peak flows used for the 1% minus and 1% plus annual chance storm events. Table 12 represents the peak discharges determined as part of this statistical analysis, which is based on the existing detailed studies.

Table 12: Peak Discharges for the Arkansas River								
Location	Drainage Area (sq. mi.)		Peak Annual Chance Discharges (CFS)					
		10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1%- Annual Chance	1%+ Annual Chance	0.2% Annual Chance
Just Upstream of West 82nd Avenue	36,015	15,270	23,000	28,270	35,080	26,727	41,439	54,240

BULL CREEK

Enhanced hydrology was performed for Bull Creek by weighting flows along the stream to flows that were generated from a detailed study that was conducted in Sterling, Kansas. The effective FIS report for Sterling, Kansas is dated September, 1997. A Letter of Map Revision (LOMR) is dated March 31, 2011. The LOMR details revisions to the Flood Insurance Rate Map (FIRM); however, no revisions were made to the FIS Report or to the flow computations. The FIS Report lists three flow change locations along Bull Creek. The peak flow for the 4% annual chance storm event for the three flow change locations were extrapolated, using the best fit curve of the peak flows for the other storm events for each subject location, as this storm event was not included in the FIS Report.

The most upstream location listed in the FIS Report is at Sterling College. The Drainage Transfer Method was utilized to interpolate flows upstream of the Sterling College location. The flows were computed using the previously described equation for unregulated streams, defined in The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites (Reference 13), which utilizes flows from only the Sterling College location.

The most downstream location listed in the FIS Report is at 11th Street. The current effective Reno County FIS Report lists flows for the mouth of Bull Creek, which is downstream of the portion of Bull Creek that is included in this study. The Uncontrolled Segment Interpolation Procedure was utilized to interpolate flows between the 11th Street location and the mouth of Bull Creek. It should be noted that the extent of this study ends just downstream of Nickerson Road, just north of Nickerson, Kansas, for Bull Creek. The flows were computed using the parameters described in Table 4 of the USGS Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations (Reference 12).

Since both interpolation methods utilize aspects of the USGS Kansas regression equations (Reference 1), the upper limit model standard error of predictions for the Kansas regression equations were used as the multiplier in determining the peak flows used for the 1% plus annual chance storm event. The peak discharges used to interpolate the peak discharges along the extent of Bull Creek are shown in Table 13.

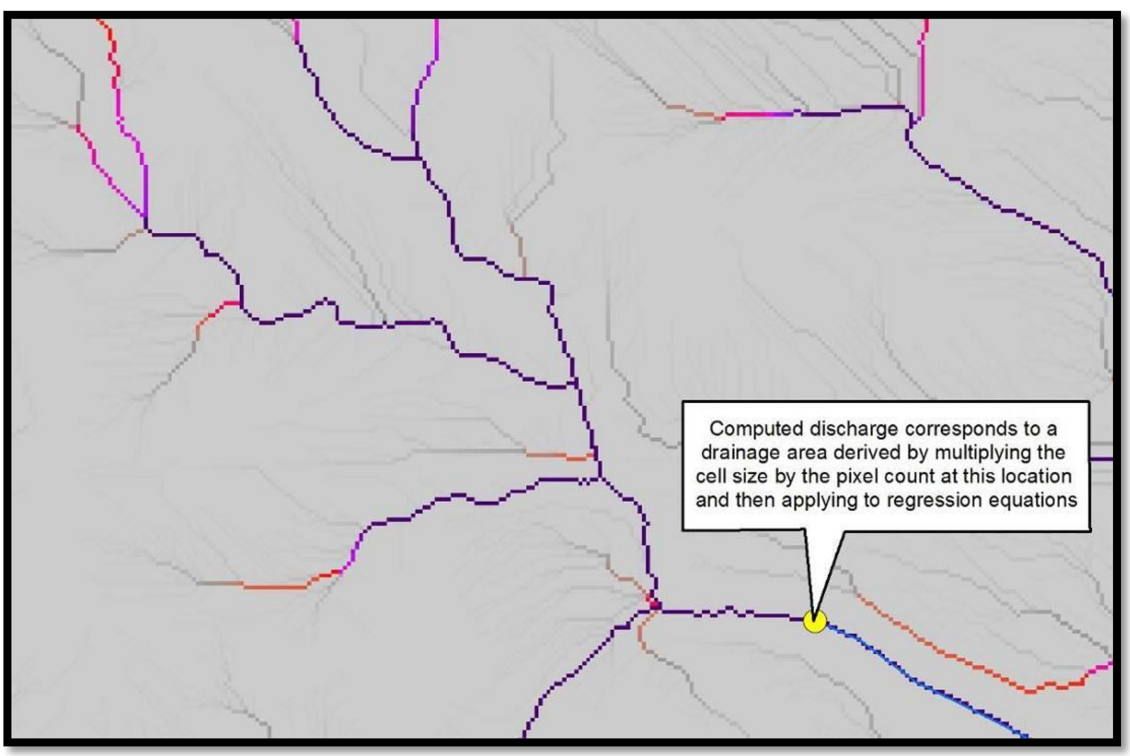
Table 13: Peak Discharges used for the Flow Distribution along Bull Creek							
Location	Drainage Area (sq. mi.)		Peak Annual Chance Discharges (CFS)				
		10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1%+ Annual Chance	0.2% Annual Chance
At Sterling College	4.82	657	825	986	1180	1735	1658
At 11th Street	20.91	1689	2200	2678	3277	4817	4779
At Mouth	58.22	5000	6450	8000	9300	13671	12500

APPROXIMATE HYDROLOGIC ANALYSIS

The hydrology for the Zone A streams that are not modeled by a detailed hydrologic method was developed by using localized regression equations, generated from the results of the detailed rainfall-runoff models that were developed for the Cow Watershed.

To prepare the drainage network, the scoped streams were adjusted based on LiDAR elevation data and aerial imagery obtained through the Kansas Data Access and Support Center. A flow accumulation grid was developed from the LiDAR data which provides a "pixel count" at desired flow change locations that represents the number of pixels flowing into it. A simple calculation is used to convert this pixel count into square miles. Figure 5 illustrates how the drainage points correspond to the flow accumulation grid.

Figure 5: Regression Analysis Discharge Calculation Example



The drainage points were located using automated processes along the stream centerline, generated from the DEM. The points were intersected with the accompanying flow accumulation grid to establish a contributing drainage area. Initial drainage points were generated every 300 feet along the stream network. Flows for the 1% annual chance storm event were then calculated for each drainage point, based on the USGS regression equations for Kansas (Reference 1).

1) For larger drainage areas: $Q_{1\%}=1.16(CDA)^{0.462}(P)^{2.250}$
2) For smaller drainage areas: $Q_{1\%}=19.80(CDA)^{0.634}(P)^{1.288}$

Where:

Contributing Drainage Area (CDA) = is the total area that contributes runoff to the stream site of interest, in square miles.

Precipitation (P) = average mean annual precipitation for the subbasin, in inches.

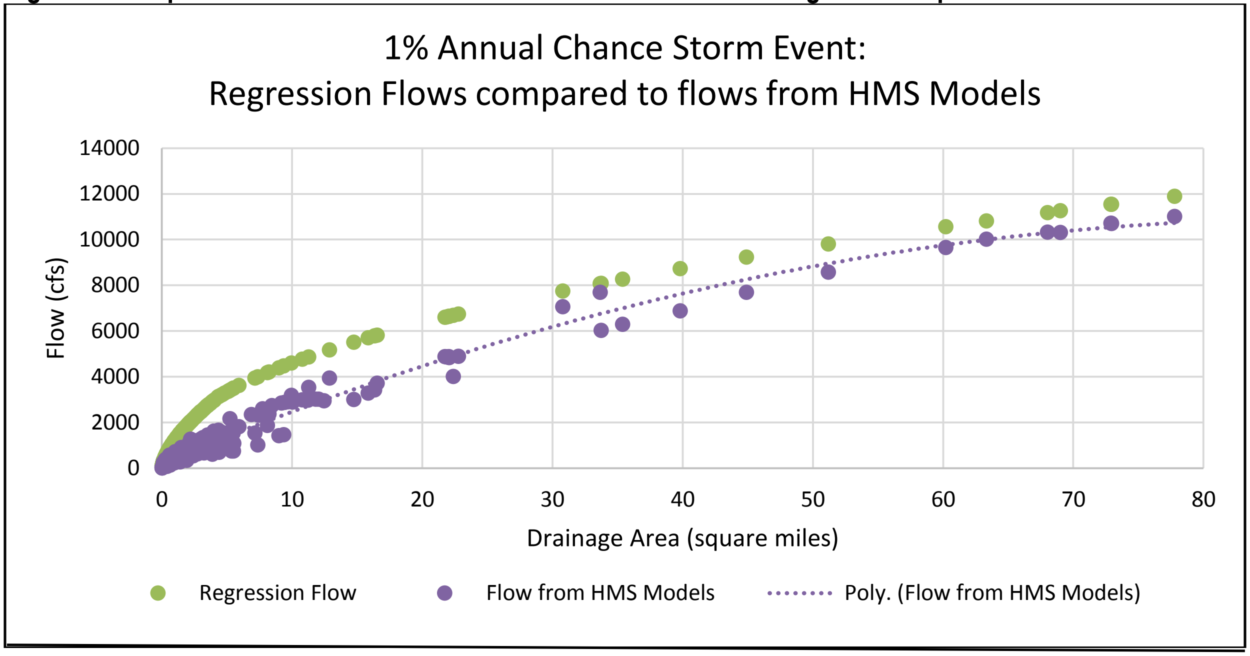
The Cow Watershed was separated into three subbasins to determine the average mean annual precipitation for each subbasin, which was then used in the regression equations.

The intersection of the two regression equations is used to determine the contributing drainage area in which to transition from the smaller drainage area equation to the larger drainage area equation.

After flows were developed using the previously described equations, the drainage point file was filtered to produce the final drainage point file that represents points at or approximately at a 10% change in flows. To establish flow change location; filtering begins at the most upstream drainage point and subsequent downstream drainage points are evaluated. The next flow change location is set to the larger of drainage point values where their percentile difference relative to previous flow value envelops a 10% change. The process is repeated until the end of the stream is reached.

In an effort to generate more accurate flows for the Zone A streams within the Cow Watershed, localized regression equations were developed, using the flows generated in the two HEC-HMS models that were created. The peak discharge and contributing drainage area for each subbasin, junction, storage area, and sink within the HEC-HMS models were evaluated, and a graph was developed to compare the peak discharge verse the contributing drainage area for the 10%, 4%, 2%, 1%, and 0.2% annual chance storm events. Figure 6 shows a comparison between the peak flows generated in the HEC-HMS models and the peak flows calculated using the USGS regression equations for Kansas for the 1% annual chance storm event. It should be noted that the visible outliers were removed from the dataset when comparing the localized regression equations to the Kansas regression equations.

Figure 6: Comparison of Flows from HEC-HMS Models and Kansas Regression Equations



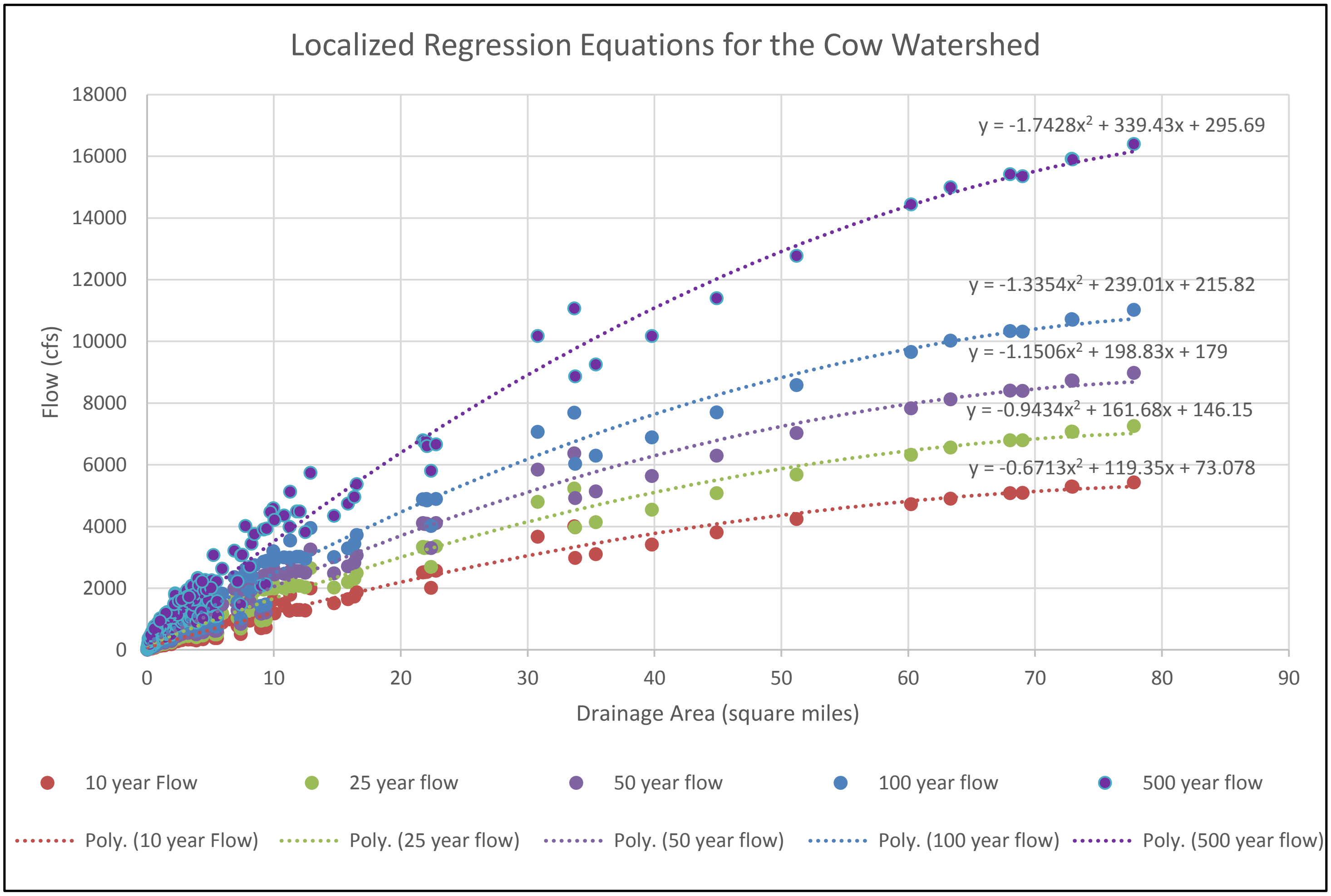
The peak flows from the HEC-HMS models are significantly lower than the calculated flows from the USGS Kansas regression equations at smaller drainage areas. The gap between the two curves lessens as the drainage area becomes larger. Characteristics of the Cow Watershed; such as the annual precipitation, relatively flat terrain, soil types, and land use types; are all contributing factors to the variation from the USGS Kansas regression equation flows. Therefore, Amec Foster Wheeler decided that it was more suitable to utilize localized regression equations when determining peak flows for the remaining Zone A streams within the Cow Watershed. This method was discussed with the Cow Creek Stakeholder Group and agreed to at a kickoff meeting before beginning the project. The peak flows for the 10%, 4%, 2%, 1%, and 0.2% annual chance storm events from the HEC-HMS models were plotted, excluding the visible outliers. A best-fit trendline was then plotted for each storm event, and was used as the localized regression equation for the associated storm event. The computed localized regression equations are as follows, and are also represented in Figure 7:

1) $Q_{10\%} = -0.6713(CDA)^2 + 119.35(CDA) + 73.078$
2) $Q_{4\%} = -0.9434(CDA)^2 + 161.68(CDA) + 146.15$
3) $Q_{2\%} = -1.1506(CDA)^2 + 198.83(CDA) + 179.0$
4) $Q_{1\%} = -1.3354(CDA)^2 + 239.01(CDA) + 215.82$
5) $Q_{0.2\%} = -1.7428(CDA)^2 + 339.43(CDA) + 295.69$

Where:

Contributing Drainage Area (CDA) = is the total area that contributes runoff to the stream site of interest, in square miles.

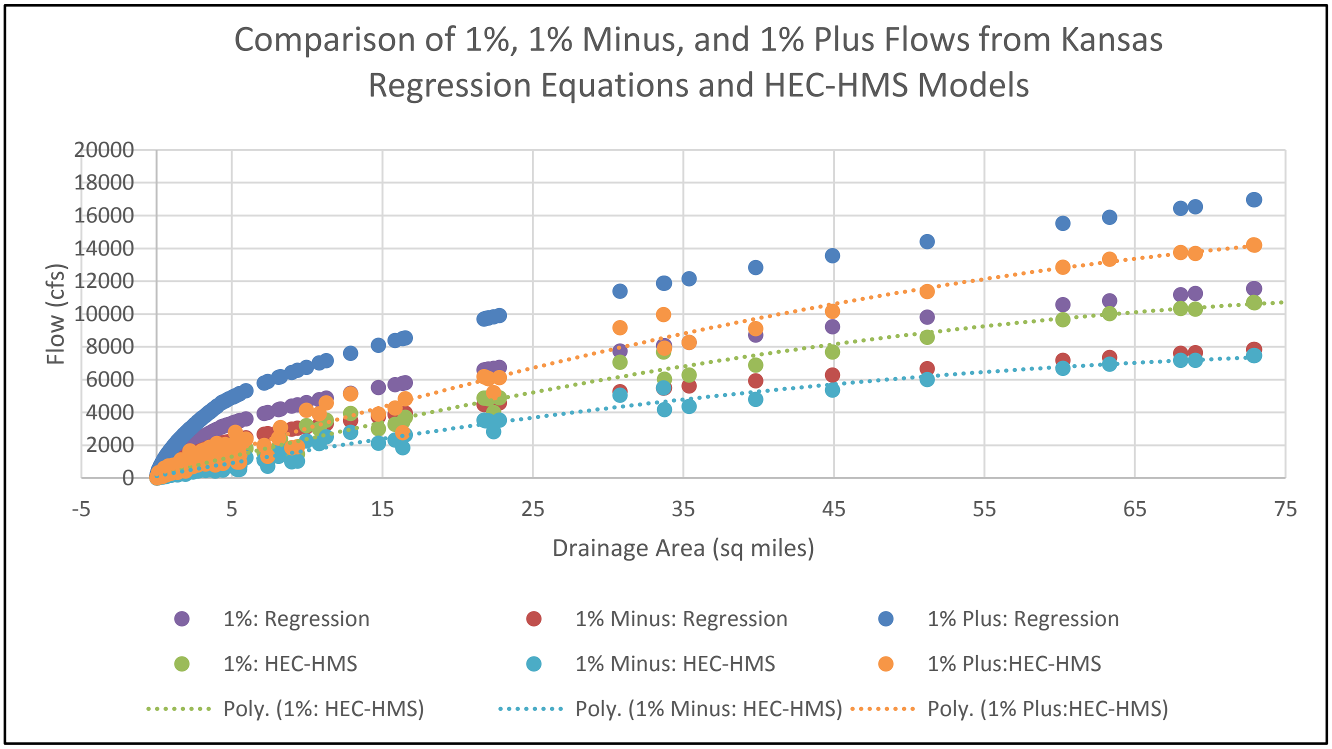
Figure 7: Localized Regression Equations for the Cow Watershed



The peak flows for the 1%, 1% minus, and 1% plus chance storm events from the HEC-HMS models were then compared to the calculated flows for the 1%, 1% minus, and 1% plus chance storm events using the USGS Kansas regression equations. The flows for the 1% minus and 1% plus events for the USGS Kansas regression equations are based on an upper and lower limit model standard error of prediction. Figure 8 shows the comparison of these flows. The 1% minus and 1% plus flows from the HEC-HMS models are less than the 1% minus and 1% plus flows calculated using the Kansas regression equations. Unfortunately, the errors associated with determining the 1% minus and 1% plus flows from the HEC-HMS models eliminate the possibility of accurately calculating a standard error of prediction from the flows generated in the HEC-HMS models to use for the hydrology of the Zone A streams in the remaining portions of the watershed. Therefore, the conservative approach was to use the peak flows calculated using the Kansas regression equations as the peak flows for the 1% plus chance storm event for the Zone A streams that are not included in a detailed hydrologic model, given that all the unknowns are intended to be a worst case scenario. The upper limit model standard error of prediction for the smaller drainage areas is 71%. The upper limit model standard error of prediction for the larger drainage areas is 47%. Since the 1% minus flows from the HEC-HMS models are less than the 1% minus flows calculated using the Kansas regression equations, it is not appropriate to believe that the flows calculated using the Kansas regression equations would encompass the actual flows during the 1% minus storm event.

This, combined with the fact that the 1% minus storm event is not a requirement for Zone A streams, led Amec Foster Wheeler into the decision of not including the flows for the 1% minus storm event in the hydrology for the Zone A streams that are not included in a detailed hydrologic study.

Figure 8: Comparison of peak flows for 1%, 1% minus, and 1% plus annual chance storm events from the Kansas Regression Equations and HEC-HMS Models



Peak flows were then calculated for each drainage point within the previously described filtered points file that was generated for the Zone A streams, using the localized regression equations for the 10%, 4%, 2%, 1%, and 0.2% annual chance storm events, and the USGS Regression Equations for the 1% plus annual chance storm event.

The peak flows along Little Cheyenne Creek, which is located below the outlet of Cheyenne Bottoms, were determined by adding the peak flows calculated by the methods described above, which exclude any contributing drainage area from Cheyenne Bottoms, to the peak flows generated for the outlet of Cheyenne Bottoms, which is within the HEC-HMS model for the Cheyenne Bottoms watershed.

CONCLUSION

As a result of these detailed analyses, peak discharges have been developed for the 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% annual chance storm events for the detailed Zone AE streams and the 10%, 4%, 2%, 1%, 1% +, and 0.2% annual chance storm events for the approximate Zone A streams. Peak discharges for the detailed Zone AE streams, developed by the detailed hydrologic analyses described in this report, are represented in Table 14 – Summary of Discharges.

TABLE 14 – SUMMARY OF DISCHARGES								
		PEAK ANNUAL CHANCE DISCHARGES (CFS)						
FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% - Annual Chance	1% + Annual Chance	0.20% Annual Chance
Arkansas River								
Just Upstream of West 82nd Avenue	36,015	15,270	23,000	28,270	35,080	26,727	41,439	54,240
Blood Creek								
At NW 10 Avenue	77.78	3736	4315	4821	5392	4441	6150	6410
At S Main Street	77.86	3730	4306	4809	5376	4432	6138	6389
Owl Creek								
At Avenue L	9.19	1180	2067	2541	3047	2127	4159	4671
At US Highway 56	9.71	1210	2081	2550	3044	2140	3970	4506
At Avenue M	10.03	1222	2068	2528	3002	2126	3994	4526
At Confluence with Owl Creek Trib 1	11.23	1306	2170	2651	3146	2230	4201	4772
At East American Road	11.80	1334	2191	2676	3168	2252	4245	4812
At Mouth	12.46	1320	2128	2614	3087	2191	3996	4528
Owl Creek Trib 2								
At Avenue L	0.10	37	84	103	121	87	156	173
At Mouth	0.23	69	155	189	223	159	288	319
Salt Creek								
At Avenue L	1.48	311	629	770	913	646	1187	1315
At Kansas & Oklahoma Railroad	1.76	335	633	755	875	650	1102	1206
At Confluence with Salt Creek Trib 1	2.19	385	729	873	1013	750	1277	1398
At US Highway 56	2.55	413	769	927	1078	792	1364	1497
At West Taylor Street	2.82	428	784	952	1109	809	1406	1544
At East American Road	3.37	461	843	1035	1212	868	1590	1835
At Mouth	4.40	596	1128	1399	1680	1162	2232	2507
Salt Creek Trib 1								
At Avenue L	0.20	46	95	115	136	97	175	193
At Kansas & Oklahoma Railroad	0.37	46	97	149	180	105	240	285
Shop Creek								
At NW 120 Road	3.16	6767	902	1083	1327	952	1718	1899
At W 9th Street	3.50	747	992	1185	1452	1047	1878	2074
At W 2nd Street	3.98	839	1115	1333	1630	1176	2110	2310
At Union Pacific Railroad	5.23	1135	1512	1787	2173	1587	2794	3073
At Mouth	5.37	1175	1567	1856	2256	1645	2902	3194
Shop Creek Trib 1								
At W Cheyenne Street	0.71	213	284	348	421	300	545	602
At W 9th Street	1.06	304	405	497	602	428	778	860
At Mouth	1.19	323	396	451	539	408	676	754
Surprise Creek								
At KS Highway 14	0.97	191	375	459	545	385	709	786
At Kansas and Oklahoma Railroad	1.55	265	547	681	821	562	1081	1200
At West Taylor Street	1.84	292	614	754	904	630	1187	1317
At West American Road	2.03	317	660	812	971	678	1274	1414
At Confluence with Surprise Creek Trib 1	7.40	892	1556	1937	2333	1602	3107	3474
At Mouth	7.50	898	1562	1944	2342	1608	3119	3488

TABLE 14 – SUMMARY OF DISCHARGES								
		PEAK ANNUAL CHANCE DISCHARGES (CFS)						
FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% - Annual Chance	1% + Annual Chance	0.20% Annual Chance
Surprise Creek Trib 1								
Approximately 1700 Feet DS of Avenue L	3.71	587	1017	1229	1444	1044	1858	2056
At Kansas and Oklahoma Railroad	4.09	609	1026	1234	1448	1051	1860	2060
At West Taylor Street	4.70	651	1079	1304	1534	1106	1977	2189
At Avenue N	5.04	673	1106	1341	1581	1135	2044	2265
At Mouth	5.26	716	1199	1454	1716	1230	2220	2460
Unnamed Slough								
At NW 10 Avenue	16.34	1487	1801	2064	2351	1868	2774	2886
At Confluence with Shop Creek	21.74	2510	3332	4113	4884	3531	6181	6791
At S Vine Street	22.03	2523	3310	4071	4849	3502	6081	6608
At S Main Street	22.05	2524	3310	4068	4847	3501	6079	6605
At East Keystone Road	22.77	2567	3355	4108	4893	3542	6132	6662

Disclaimer: As mapping tasks are completed, the potential for minor changes to the information submitted in the hydrology submission and within this report may become necessary. The data provided in this submission and report may not be completely representative of the hydraulics used to produce the final map product. Therefore, this report and the hydraulics submission should be considered as draft. This submission should be considered a complete step in progress but not necessarily the final product since the post preliminary process is not yet completed and the floodplain maps are not yet effective.

REFERENCES

1. Rasmussen, P.P., and Perry, C.A., 2000. *Estimation of Peak Streamflows for Unregulated Rural Streams in Kansas*: U.S. Geological Survey Water Resources Investigations Report 00-4079, http://ks.water.usgs.gov/pubs/reports/wrir.00-4079.html.

2. US Army Corps of Engineers, Hydrologic Engineering Center, 2015, HEC-HMS Hydrologic Modeling System, Version 4.1, July 2015.

3. US Army Corps of Engineers, Hydrologic Engineering Center, 2010, HEC-GeoHMS Geospatial Hydrologic Modeling Extension, Version 10.2, October 2010.

4. ArcHydro for ArcGIS 10.2.2, Version 10.2, January 2014.

5. Perica, S., D. Martin, S. Pavlovic, I. Roy, M. St. Laurent, C. Trypaluk, D. Unruh, M. Yekta, G. Bonnin (2013). *NOAA Atlas 14 Volume 8, Precipitation-Frequency Atlas of the United States, Midwestern States*. NOAA, National Weather Service, Silver Spring, MD.

6. USDA, NRCS, Web Soil Survey, http://websoilsurvey.nrcs.usda.gov/app.

7. USDA, NRCS, National Land Cover Dataset, http://www.mrlc.gov/, 2011.

8. USDA, NRCS, *TR-55 Urban Hydrology for Small Watersheds*, 1986.

9. USDA, NRCS, National Engineering Handbook Part 630.

10. Interagency Committee on Water Data, 1981. *Guidelines for Determining Flood Flow Frequency: Bulletin 17B of the Hydrology Subcommittee (revised and corrected)*.

11. US Army Corps of Engineers, Hydrologic Engineering Center, 2010, HEC-SSP Statistical Software Package, Version 2.0, October 2010.

12. Perry, C.A., Wolock, D.M., and Artman, J.C., 2004; *Estimations of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations*; U.S. Geological Survey Scientific Investigation Report 2004-5003, http://pubs.usgs.gov/sir/2004/5033.

13. Ries III, K.G., 2007; *The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungagged Sites*: U.S. Geological Survey Techniques and Methods 4-A6, http://pubs.usgs.gov/tm/2006/tm4a6.

14. USGS, National Water Information System Site Information for USA: Site Inventory, http://waterdata.usgs.gov/nwis/inventory.